Universität Zürich
Zentrum für Zahnmedizin
Klinik für Kaufunktionsstörungen, abnehmbare Rekonstruktionen, Alters- und Behindertenzahnmedizin
Direktor: Prof. Dr. L.M.Gallo

Arbeit unter der Leitung von Prof. Dr. med. dent. S.Palla

In vivo testing of resin-bonded composite rest seats for removable partial dentures

INAUGURAL-DISSERTATION
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vorgelegt von
Sylvia Phuong Leuthold
von Oberrieden ZH

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1. Abstract

Aim. Incisal or cingulum rest seats of removable partial dentures in the front teeth area can be problematic as they may lead to poor aesthetic and occlusal interferences. In addition the at times insufficient depth of enamel does not allow the preparation of a sufficient ledge depth without exposing the dentin. The aim of this study was to investigate whether resin-bonded composite rest seats (RBCRSs) withstand mechanical and thermal stress in vitro.

Materials and Methods. 48 canines were provided with a RBCRS built by means of a soft splint and a microhybrid composite. The volume and the bonded area of the RBCRSs were measured by means of the optoelectronic Cerec Camera 3D and the Cerec 3 Volume Program. The teeth were divided into 3 groups of each 16 teeth and they all underwent thermal and mechanical fatigue stress in a computed controlled masticator (CoCoM). The loading of the RBCRSs was performed with a frequency of 1.7Hz, the loading arm remaining at all times in contact with the RBCRSs. The thermal stress was assured by alternately filling the chambers with a 1-mMol NaCl-solution of 5°C-55°C-5°C. The teeth of group 1 were loaded 1.2Mio times with a force of 49N that simulated the exposure of the oral rest seat to mastication during 5 years. The teeth of group 2 were loaded 1.2Mio times with a force of 75N while those of group 3 were loaded 2.4Mio times with a force of 49N. This last loading condition simulated the exposure of the oral rest seat to mastication during 10 years. After the thermocycling the RBCRSs were sheared off in a universal testing machine in order to determine the flexure load at failure. The force was applied with a flat piston with a crosshead speed of 1 mm/min and recorded until failure. The different fracture types were determined by means of a binocular loupe and the fracture of five samples were analyzed also under a scanning electron microscope. Differences in flexure load at failure, bonding area and volume for each group were analyzed by one-way ANOVA and the Scheffé post-hoc test ($p<0.05$). Associations between flexure load at failure and bonding area/volume were investigated by Spearman rho correlation.

Results. None of the RBCRSs broke off or detached after loading in the CoCoM. The overall flexure load at failure was 1124.4 $\pm$ 295N, the flexure load at failure of group 2 being significantly larger than group 1 ($p<0.05$). The flexure load at failure was independent of the bonding surface area.

Conclusions. The RBCRS withstood the thermal and mechanical stress in vitro during a simulated exposure to chewing load up to 10 years.

2. Zusammenfassung

Ziel. In der abnehmbaren Teilprothetik können inzisale oder orale Auflager bei den Pfeilerzähnen zu unbefriedigender Aesthetik und okklusalen Interferenzen führen. Zudem kann eine manchmal ungenügende Schmelzdicke der Pfeilerzähne die Auflagerpräparation mit ausreichender Tiefe und ohne Dentinexposition verunmöglichen. Das Ziel dieser Studie ist es zu prüfen ob adhäsiv befestigte Kompositauflager (ABKA) in vitro der mechanischen und thermischen Belastung standhalten können.

Material und Methoden. 48 Eckzähne mit einem ABKA, das mittles einer Tiefziehschiene und microhybridem Komposit modelliert worden war, wurden verwendet. Die Volumen und Klebeflächen der ABKA wurden mittels der optoelektronischen Cerec Camera 3D und des Cerec 3 Volumen Programms gemessen. Die Zähne wurden in 3 Gruppen an je 16 Zähnen aufgeteilt und im Kausimulator der mechanischen und thermischen Belastung ausgesetzt. Die ABKA wurden mit einer Frequenz von 1.7Hz über einen immerwährend in Kontakt bleibenden Stempel belastet. Die thermische Belastung wurde durch alternierendes Füllen der Probekammern mit einer 1-mMol NaCl-Lösung von 5°C-55°C-5°C simuliert. Die Zähne der 1.Gruppe wurden 1.2Mio Mal mit einer Kraft von 49N, was einer intraoralen Belastungsdauer von 5 Jahren entspricht, belastet. Die Zähne der 2.Gruppe wurden 1.2Mio Mal mit einer Kraft von 75N und die Zähne der 3.Gruppe wurden 2.4Mio Mal mit einer Kraft von 49N belastet. Diese letzte Einstellung entsprach der intraoralen Kaubelastung von 10 Jahren. Danach wurden alle ABKA mit einem Stempel und einer Belastungsgeschwindigkeit von 1mm/min in einer Universalmaschine abgeschert um die Bruchlast zu bestimmen. Der Kraftverlauf wurde graphisch festgehalten. Die Art der Frakturen wurde unter dem Binocular bestimmt und 5 Proben wurden zusätzlich unter dem Rasterelektronenmikroskop analysiert. Der Mittelwertvergleich für die Bruchlast, die Klebefläche und das Volumen wurde mittels die ANOVA und dem Scheffé post-hoc Test ($p<0.05$) gemacht. Mögliche Korrelationen zwischen der Bruchlast und der Klebefläche bzw. dem Volumen wurden mittels dem Spearman rho untersucht.

Resultate. Keines der ABKA wies eine Fraktur oder Adhäsionsverlust nach der Belastung im Kausimulator auf. Die allgemeine Bruchlast betrug 1124.4 $\pm$ 295N, die Bruchlast von Gruppe 2 wies einen signifikant grösseren Unterschied zur Gruppe 1 auf ($p<0.05$). Die Bruchlast war unabhängig von der Klebefläche und dem Volumen.

Konklusion. Die ABKA haben der thermischen und mechanischen Kaubelastung in vitro für eine intraorale Belastungszeit von 10 Jahren standgehalten.

3. Introduction

A partially edentulous patient is frequently rehabilitated by means of a removable partial denture (RPD) often secured to the anterior teeth by means of occlusal rests. These assure the vertical denture support in order to prevent the denture base to settle into the mucosa. The commonly used rest seats in the anterior front teeth area are the cingulum and the incisal. The cingulum rest seat is often preferred to the incisal one because it provides a better aesthetic. However, the preparation of a sufficient ledge depth of about 1 mm quite often leads to dentin exposure (Jones et al. 1992) and therefore to an increased caries risk.

The achievements in adhesive technique led several authors to propose the use of metal resin-bonded cingulum rest (Czuszak and Meyer 1989; Janus et al. 1985; Latta 1988; Lyon 1985; Seto et al. 1985) or resin-bonded composite rest seat (RBCRS) to support the framework in the front teeth area (Czuszak and Meyer 1989; McArthur 1986; Toth et al. 1986; Lopes et al. 2007). The RBCRS has several advantages: better aesthetic, preservation of tooth structures and reduced costs because of no need of additional laboratory work.

The purpose of this study was to investigate in vitro whether the resin-bonded composite rest seats withstand the thermal stress and the occlusal forces developed during mastication for a period up to 10 years.

4. Materials and methods

Forty-eight extracted maxillary or mandibular non-carious canines were collected. They were cleaned from attached soft tissue and calculus with a scaler and polished with a mixture of pumice and toothpaste and stored in tap water at 36°C (Tonsun et al. 2006).

4.1. Preparation of the resin-bonded cingulum rest seat

In order to standardise the size of the volume and of the adhesive surface of the RBCRSs a reference cingulum rest seat was build up in composite. Thereafter an impression of this reference tooth was taken with silicon material to provide a plaster tooth cast. Finally, the negative mould of the test tooth was obtained with a thermoform Erkodent flexible sheet (Erkoflex 1,5mm, Erkodent, Pfalzgrafenweiler, Germany). The sheet flexibility was necessary in order to allow its adaptation to the various canine forms.

The tooth crown was first polished with prophy paste without fluoride (Cleanic®, KerrHawe, Bioggio, Switzerland), rinsed and air dried. The two-step total-etch adhesive Heliobond (Ivoclar Vivadent, Schaan, Liechtenstein) (Inoue et al. 2003; Brackett et al. 2006; Van Landuyt et al. 2007) and the fine particle microhybrid composite Tetric A3 (Ivoclar Vivadent, Schaan, Liechtenstein) were used to fabricate the RBCRS. The cervical half of the lingual enamel surface was etched for 120 seconds with a 37% phosphoric acid gel (Ultraetch, Ultradent Products Inc., South Jordan, USA), rinsed for 60 seconds and air dried. The adhesive was applied with a brush on the etched area, let rest for 30 seconds, gently air blown to achieve an optimally thin layer and light cured for 60 seconds with the polymerisation lamp (Bluephase 16i, Ivoclar Vivadent, Schaan, Liechtenstein) in the low power mode with a light output of 650 mW/cm². The rest seat was build up in two steps. First a composite layer of 1mm thickness was placed freehand on the lingual surface and light cured for 40 seconds in the high power mode with a light output of 1600 mW/cm². Thereafter, composite was placed in the soft plastic tray. This was then positioned on the tooth as accurately as possible and the composite light cured for 60 seconds in high power mode. Finally, the soft splint was removed, composite excesses eliminated and the rest seat polished.

4.2. Measurement of the size of the RBCRS' volume and adhesive surface

This was done by means of an optical three-dimensional system (Windisch et al. 2007). An optical imprint of each tooth was taken with the optoelectronic Cerec Camera3D before and after the RBCRS build up (pre- and postoperative situation) (Sirona The Dental Company, Bensheim, Germany) (Mehl et al. 2009; Luthardt et al. 2005). In order to increase the visual contrast necessary for the optical imprint a special silicone tooth holder with a textured surface was fabricated for each sample. As a precise imaging requires a non-reflective surface, holder and tooth were coated with a thin layer of white scan spray (Cerec Optispray, Sirona, Bensheim, Germany). The Cerec Camera3D was manually placed with a supporting aid over the prepared tooth and the optical imprint taken. The Cerec 3 Volume Program (Cerec software 2.80 R2400 Volume Difference, Sirona, Bensheim, Germany) superposed the pre- and postoperative imprints and calculated the volume and the adhesive surface of the composite rest seat (Fig. 1).

4.3. Resin-bonded cingulum rest seat loading in the chewing simulator machine

Each tooth was fixed on an aluminium holder by means of selfcuring acrylic (Paladur, Hereus Kulzer, Dübendorf, Switzerland) so that the horizontal surface of the rest seat was perpendicular to the force vector during loading. After mounting the aluminium holder in the chambers of the computer controlled masticator (CoCoM) (Fig. 2) the teeth were subjected to thermal and mechanical fatigue stress (Krejci et al. 1990). The mechanical stress was provided by a loading arm with a fixed 4mm diameter ball at its end that remained in contact with the composite rest seat during the whole procedure. The loading was performed with a frequency of 1.7Hz. The thermal stress was assured by alternately filling the chambers with a 1-mMol NaCl-solution of 5°C-55°C-5°C with 4min per thermal cycle.

The 48 teeth were randomly assigned by a person blind to the study purpose into three groups (group 1, 2 and 3) of sixteen teeth each (n=16). The three groups of teeth were subjected to the following loading conditions. 16 teeth were loaded 1.2Mio times with a force of 49N that simulated the exposure of the oral rest seat to mastication during 5 years (group 1). The teeth of group 2 were loaded 1.2Mio times with a force of 75N while those of group 3 were loaded 2.4Mio times with a force of 49N. This last protocol simulated an exposure of the cingulum rest seats to chewing during 10 years.

4.4. Fracture testing of the resin-bonded composite rest seats

After the experiment in the computer controlled masticator the samples were loaded in a universal testing machine (Zwick/Roell Z010, Ulm, Germany). The load was applied as good as possible to the enamel-composite border with a flat piston parallel to the tooth long axis (Fig. 3). The force was applied with a crosshead speed of 1 mm/min and recorded until failure. To avoid force peaks, a 0.5 mm tin foil (Dentaurum, Ispringen, Germany) was placed between the composite and the loading piston.

The fractured area was examined by means of a binocular loupe with a magnification of 2.7 times (starVision SV1, starMed, Grafing, Germany) in order to determine whether the fracture was adhesive, cohesive within the enamel or within the composite or a combination. In addition five teeth with a clear fracture were analyzed also under the scanning electron microscope (VEGA TS 5136 XM, Tescan, Dortmund, Germany).

4.5. Statistical analysis

Preliminary analyses consisted of descriptive statistics (mean, standard deviation, 95% confidence interval (95% CI) for normal data and frequency distribution for discrete variables).

Differences in the flexure load at failure, in the size of the bonded area and in the size of volume among the groups were analyzed by means of a one-way ANOVA and the Scheffé post-hoc test. The correlation between the flexure load at failure and the size of volume and the flexure load at failure and the size of bonded area respectively was investigated by means of the Spearman rho correlation for each group separately. The fracture types were expressed in percentage of the total samples. All analyses were performed by commercial software (SPSS version 18.0, Chicago, Il, USA). Type I error was set at $p \leq 0.05$ (two-tailed).

5. Results

The overall mean (±SD) of the bonded area of the rest seats was 22.4 ± 3.1mm² and the differences between groups were not statistically significant ($p<0.05$) (Table 1, Fig. 4). Neither fracture within the bonded rest seats nor adhesive loss of the bonded rest seats were observed after the thermal and mechanical fatigue stress in the computer controlled masticator.

The overall mean (±SD) of the volume of the rest seats was 25.6 ± 5.2mm³ and the differences between groups were not statistically significant ($p<0.05$) (Table 1, Fig. 5).

The overall mean flexure load at failure (±SD) was 1124.4 ± 295N (Table 1, Fig. 6). The post-hoc Scheffé test indicated that the flexure load at failure was statistically larger in group 2 than 1 ($p<0.05$) (Table 2).

There was no correlation between the size of the bonded area and the flexure load at failure (Fig. 7) and no correlation between the size of volume and the flexure load at failure (Fig. 8).

The majority of fractures were a combination of adhesive and cohesive within the composite (68.8% over all three groups) followed by a combination of adhesive and cohesive within the enamel and composite (25% over all three groups) (Table 3). An example of the fracture type is visible in Fig. 9 (SEM).

6. Discussion

The main finding of the study was that all bonded rest seats withstood the thermocycled loading for a testing period corresponding to chewing during 5 years with a loading force of 75N and of 10 years with a loading force of 49N. These loading forces were chosen based on data reporting that the occlusal forces developed during chewing in dentate and partially dentate subjects lie below 80N (DeBoever 1978; Graf 1975) and 27N respectively (Yurkstas and Curby 1953; Maxfield et al. 1979).

The flexure load at failure of all samples was higher than the average maximum clenching force recorded in dentate subjects that is approximately 650 N (Gibbs et al. 1981; Neil et al. 1989). The flexure load at failure of group 2 was significantly larger than that of group 1 for we do not have a plausible explanation especially considering that the loading force applied to the RBCRSs of group 2 was higher than that applied to the RBCRSs of group 1 while the loading duration was the same for both groups.

Interestingly the size of the bonded area was not associated with the flexure load at failure. 95% of the bonding areas (mean $\pm$ 2 SD) had a bonding area of at least 16.2mm^2. This implies that a bonding area of approximately 16mm^2 should be clinically sufficient to provide adequate retention for the RBCRSs. Further studies are necessary to assess the minimum bonding area size in order to provide guidelines for the provision of RBCRSs on smaller teeth, like the lower central and laterals or the upper front teeth in case of a deep bite. Adequate bonding with smaller adhesive areas has been reported previously (Toth et al. 1986 a,b). To the best of our knowledge these are the only two studies that investigated in vitro the loading resistance of resin-bonded composite rest seats. There are, however, significant methodological differences between those and our study. Indeed, in our study the average bonding surface was about 2.5 times larger (8.44 $\pm$ 1.42mm^2 vs. 22.4 $\pm$ 3.1mm^2), the loading force for the thermocycling was 2-3 times higher (24.5N vs. 49N and 75N). Also the results differed as far as the average flexure load at failure being in our study about 3 times larger (343N $\pm$ 78N vs. 1124 $\pm$ 259N). This is likely due to improved adhesive technique and internal strength of the composite (Abe et al. 2005; Ferracane 2010; Ilie et al. 2009).

The results obtained from this in vitro study confirm the feasibility of using the RBCRSs to sustain the occlusal load of a removable partial denture. Clinically, this has already been proved by Maeda et al. (2008) and correspond to our clinical experience.

Two limitations of this study were the use of only one bonding system and composite for the fabrication of the RBCRSs and the use of a relatively large bonding area. Further investigations of bonding systems could elucidate alternative methods resulting in cost effectiveness and treating time reduction. Further investigations of fracture toughness of dental composite could minimize the occurrence of cohesive fracture in composite (Drummond 2008; Ilie et al. 2011; Inoue et al. 2003; Manhart et al. 2000; Watanabe et al. 2006) though this in vitro study occurred in a safe range as the flexure load at failure was much higher than the forces developed during mastication. One further question that still remains to be answered concerns the wear of the RBCRS through the metal frame, which according to an in vitro study seems to be quite low if microfilled composites are used (Hemirudin et al. 2007).

6.1. Implication for the clinic

The building of the RBCRS is simple for dentists used to composite fillings. The cost effectiveness and time saving of the postulated method and the main advantage of preserving the integrity of the tooth surface are strongly supporting this alternative way of constructing a rest seat for a RPD. Therefore the RBCRS should be considered in the planning of a RPD.

6.2. Conclusion

This in vitro study indicated that all bonded rest seats withstood the thermocycled loading for a testing period corresponding to chewing during 5 years with a loading force of 75N and during 10 years with a loading force of 49N. The force at which the resin bonded composite rest seats failed was much higher than the forces normally developed during mastication.

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8. Tables

Group	Bonded area (mm^2)		Volume (mm^3)		Flexure load at failure (N)	
	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI
1	22.0(4.2)	(19.7,24.3)	27.8(5.9)	(24.6,31.0)	995.8(226.8)	(874.9,1116.7)
2	22.9(2.8)	(21.4,24.5)	23.4(4.7)	(20.8,26.0)	1282.9(243.5)	(1153.2,1412.7)
3	22.3(1.8)	(21.3,23.3)	25.5(4.1)	(23.3,27.8)	1094.6(232.4)	(970.7,1218.5)
Total	22.4(3.1)		25.6(5.2)		1124.4(259)	

Table 1. Mean, Standard deviation (SD) and Confidence Interval (CI) of Bonded area, volume and flexure load at failure.

(I) Group	(J) Groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-287.17625*	82.85399	.005	-496.9235	-77.4290
	3	-98.86375	82.85399	.496	-308.6110	110.8835
2	1	287.17625*	82.85399	.005	77.4290	496.9235
	3	188.31250	82.85399	.087	-21.4347	398.0597
3	1	98.86375	82.85399	.496	-110.8835	308.6110
	2	-188.31250	82.85399	.087	-398.0597	21.4347

* $p < 0.05$ level.

Table 2. Sheffé post-hoc test for flexure load at failure.

	adhesive (a)	cohesive enamel (ce)	cohesive composite (cc)	a-ce	a-cc	a-ce-cc
Group 1			1(2.1%)	1(2.1%)	12(25%)	2(4.2%)
Group 2			1(2.1%)		7(14.6%)	8(16.7%)
Group 3					14(29.2%)	2(4.2%)
Total			2(4.2%)	1(2.1%)	33(68.8%)	12(25%)

Table 3. Fracture types and percentage distribution. a: adhesive; ce: cohesive within the enamel; cc: cohesive within the composite; a-ce: combination of adhesive and cohesive within the enamel; a-cc: combination of adhesive and cohesive within the composite; a-ce-cc: combination of adhesive and cohesive within the enamel and composite.

9. Figures

Fig. 1. Optical imprint of a tooth with a resin-bonded rest seat.

Fig. 2. Tooth with the RBCRS in the computer controlled masticator.
The loading arm contacts the RBCRS.

Fig. 3. Tooth under the loading arm of the universal testing machine.
The loading arm contacts the tin foil in between.

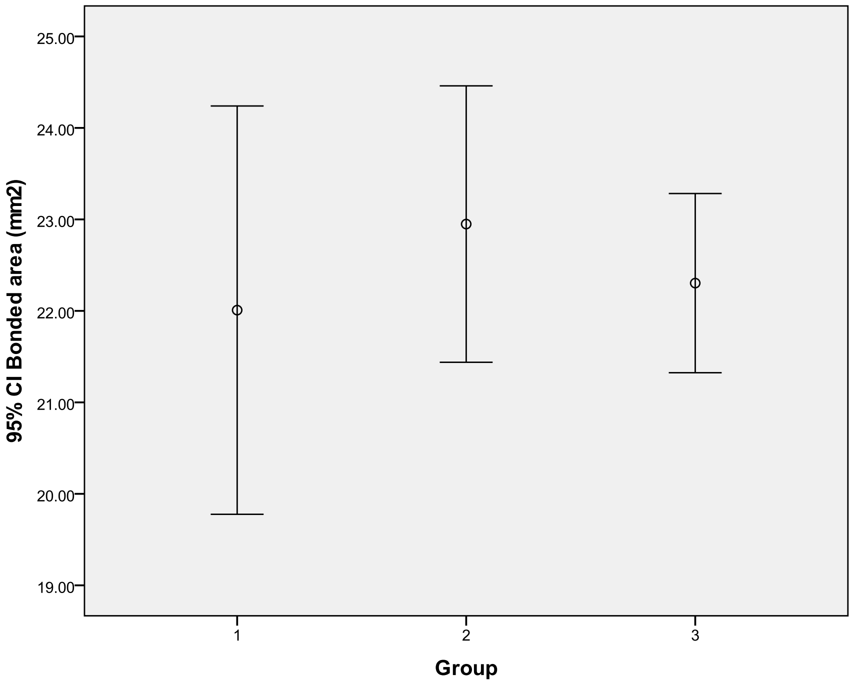

Fig. 4. Mean value and standard deviation of the bonded area in mm^2 for the three groups.

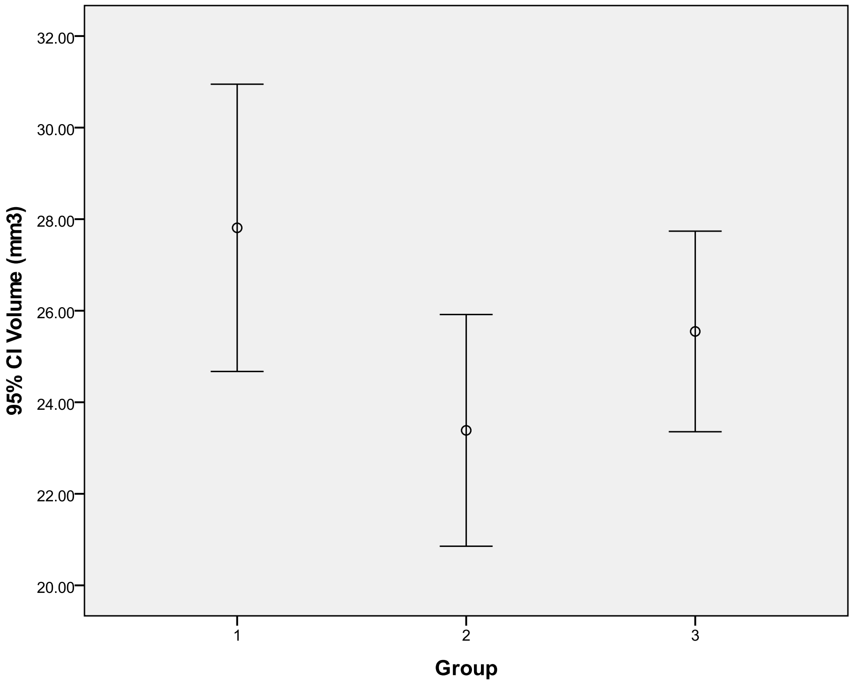

Fig. 5. Mean value and standard deviation of the Volume in mm³ for the three groups.

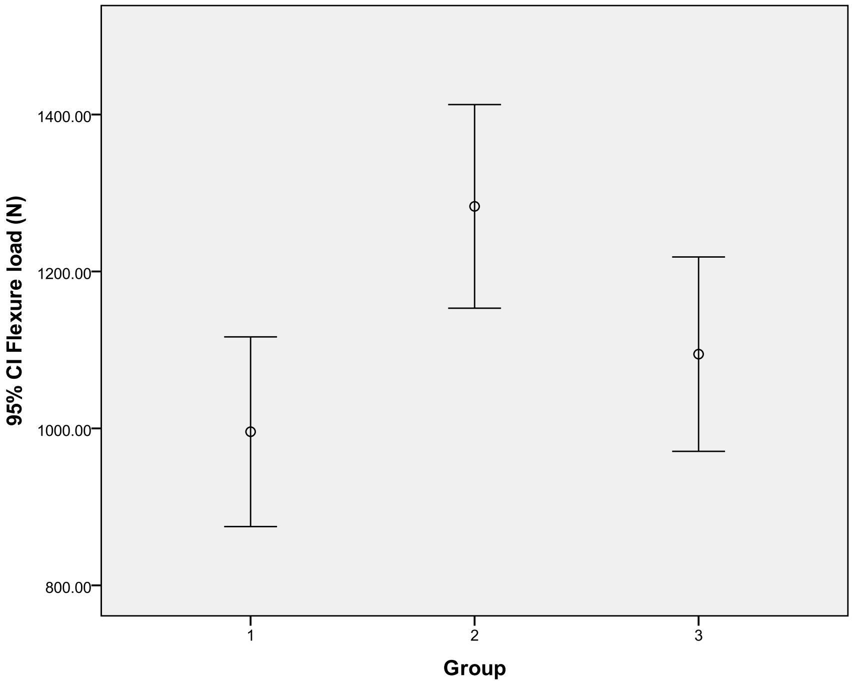

Fig. 6. Mean value and standard deviation of the flexure load at failure in N for the three groups.

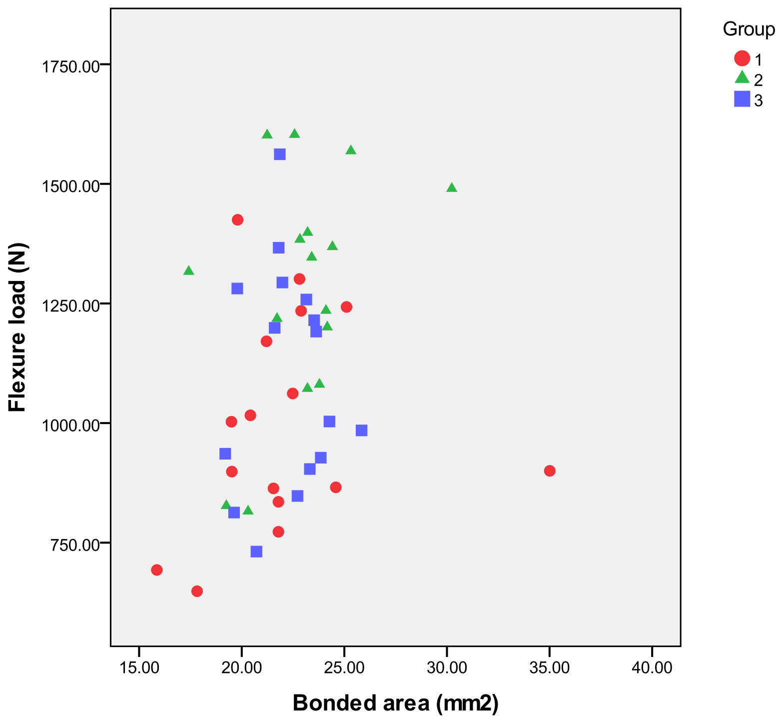

Fig. 7. Scatterplot: Flexure load at failure versus bonded area size.

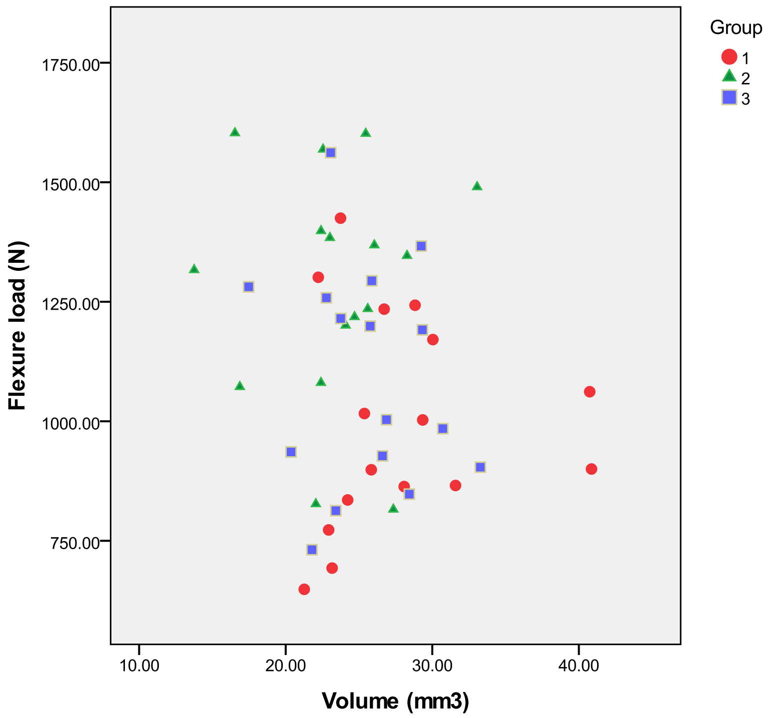

Fig. 8. Scatterplot: Flexure load at failure versus volume size.

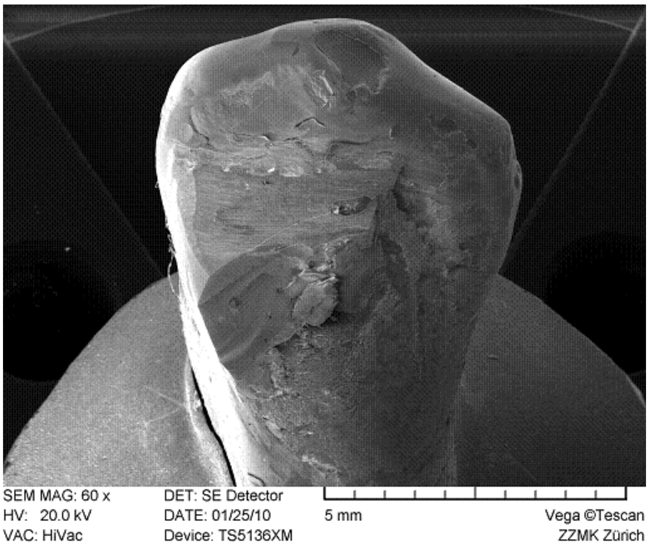

Fig. 9. Fracture analyse under scanning electron microscope.